

United States Air Force Research Laboratory



SCHEDULING AIRCREWS 1: INTRA-THEATER 24/7 OPERATIONS

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May 2005

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20050630 130

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.				
1. REPORT DATE (DD-MM-YYYY) May 2005		2. REPORT TYPE Interim		3. DATES COVERED (From - To) 1 Jun -30 Sep 2004
4. TITLE AND SUBTITLE SCHEDULING AIRCREWS 1: INTRA-THEATER 24/7 OPERATIONS			5a. CONTRACT NUMBER	
			5b. GRANT NUMBER	
			5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) James C. Miller			5d. PROJECT NUMBER 7757	
			5e. TASK NUMBER P9	
			5f. WORK UNIT NUMBER 04	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Human Effectiveness Directorate Biosciences and Protection Division Fatigue Countermeasures Branch Brooks City-Base, TX 78235			8. PERFORMING ORGANIZATION REPORT	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Human Effectiveness Directorate Biosciences and Protection Division Fatigue Countermeasures Branch 8248 Chennault Path Brooks City-Base, TX 78235			10. SPONSOR/MONITOR'S ACRONYM(S) AFRL/HE	
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-HE-BR-TR-2005-0074	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.				
13. SUPPLEMENTARY NOTES				
14. ABSTRACT Aircrew fatigue problems existed in 24/7, intra-theater, tactical airlift operations. One reason for the high levels of fatigue was the irregularity of the schedule for a given crew across days. A rotating shift schedule approach was recommended: slow rotation if adequate day-sleep facilities are available; otherwise, rapid rotation schedule to minimize exposure to inherently debilitating night work. Seven scheduling principles were applied including a normal, maximum crew duty period of 14 hours, and scheduling an aircrew such that their show time does not differ more than +/-1 hour on successive days. Five scheduling concepts were used to produce examples of one slowly-rotating schedule and one rapidly-rotating schedule				
15. SUBJECT TERMS Fatigue model, software usability, FAST, SAFTE, data input, controls and displays				
16. SECURITY CLASSIFICATION OF: UNCLASSIFIED			17. LIMITATION OF ABSTRACT UNCLAS	18. NUMBER OF PAGES 24
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED	19a. NAME OF RESPONSIBLE PERSON Dr. James C. Miller	
			19b. TELEPHONE NUMBER (include area code) 210-536-2742	

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PREFACE

This Technical Memorandum covers the project period of 1 June 2004 to 30 September 2004. The work was performed under Job Order Number 7767P904. The project manager was Dr. James C. Miller, Senior Research Physiologist, Fatigue Countermeasures Branch, Biosciences and Protection Division, Air Force Research Laboratory (AFRL/HEPF).

This Technical Memorandum was written in response to aircrew fatigue problems for around-the-clock (24/7) intra-theater operations by tactical airlifters, identified to this Branch by the Safety Office of United States Central Command Air Forces (CENTAF/SE), Shaw AFB, SC. The author drew upon 30 years of experience in applied research concerning human operator fatigue in transportations and shiftwork systems, preceded by 2000 hours of USAF C-130 pilot time, including 700 hours of combat time.

This is one of several case-studies of operations produced by this Branch at the end of fiscal year 2004 using the U.S. Department of Defense Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) applied model¹. SAFTE integrated the effects upon cognitive performance effectiveness of length of prior wakefulness, amount of sleep and circadian rhythm. In turn, the SAFTE applied model was implemented in the Windows® program, Fatigue Avoidance Scheduling Tool (*FAST*TM, NTI Inc., Dayton OH). For this case study, we used *FAST*TM beta version 1.0.13 with the following parameter values:

Model Parameters	Values
24-hr rhythm acrophase	18
12-hr rhythm phase offset	3
Relative amplitude of 12-hr rhythm	0.5
Sleep propensity mesor	0
Sleep propensity amplitude	0.55
Maximum sleep accumulation per minute	3.4
Performance rhythm amplitude (fixed %)	7
Performance rhythm amplitude (variable %)	5
Reservoir capacity	2880
Feedback amplitude	0.0031200
Sleep inertia time constant	0.04
Maximum inertia following awakening (%)	5
Performance use rate	0.5
Slow recovery	
K1	0.22
K2	0.5
K3	0.0015
Sleep environment	
Excellent	1
Moderate	0.83
Poor	0.5

¹ Hursh SR, Redmond DP, Johnson ML, Thorne DR, Belenky G, Balkin TJ, Storm WF, Miller JC, Eddy DR. (2004). Fatigue models for applied research in warfighting. *Aviation, Space and Environmental Medicine*, 75(3), Section II, Supplement, pp. A44-A53.

SUMMARY

Aircrew fatigue problems existed in around-the-clock (24/7), intra-theater, tactical airlift operations. One reason was the irregularity of the schedule for a given crew across days. There are three approaches to 24/7 scheduling: fixed shifts, rapidly rotating shifts and slowly rotating shifts. The assumption made here was that some sort of a rotating shift was necessary. Seven scheduling principles were applied:

- Set a normal, maximum crew duty period (CDP) of 14 hours to allow a crew to work on a 24-h cycle (AFI 11-202, Paragraph 9.7.4.1).
- Follow each CDP longer than 14 h with a day off (AFI 11-202, Paragraph 9.7.6.2).
- Schedule either:
 - A long sequence of night shifts in a slowly-rotating schedule (with adequate sleep facilities) to allow acclimation to night work and day sleep, or
 - A minimum number of consecutive night shifts in a rapidly-rotating schedule to minimize exposure to night work where sleeping facilities are inadequate (see Appendix E).
- In a rapidly-rotating system, follow each night shift with 24 hours off.
- Schedule long, contiguous periods of time off.
- Assure equity by giving all aircrews equal demands for long CDPs and night work and equal access to day work and good quality time off.
- Schedule an aircrew such that their show time does not differ more than +/-1 hour on successive days to allow the crew to continue on a 24-h cycle.

Five scheduling concepts were used to produce an example of a slowly-rotating schedule and an example of a rapidly-rotating schedule. The concepts were:

- Number of crews and manning ratio,
- The relative numbers of work and free days,
- Crew duty period (CDP) and crew workload,
- The sequence of work and free days, and
- Show times.

The memo includes one example of a slowly-rotating schedule for crews with good day-sleep quarters and one example of a rapidly-rotating schedule for crews with poor day-sleep quarters. Schedules such as these provide equity across crews, predictability for a crew, and long, contiguous periods of time off that should help combat the onset of chronic fatigue.

SCHEDULING AIRCREWS 1: INTRA-THEATER 24/7 OPERATIONS

INTRODUCTION

Aircrew fatigue problems in around-the-clock (24/7), intra-theater, tactical airlift operations were identified to this Branch and reported elsewhere². This Technical Memo (TM) provides guidelines for aircrew schedulers. The guidelines include one example of a slowly-rotating schedule for crews with good sleep quarters and one example of a rapidly-rotating schedule for crews with poor sleep quarters. Schedules such as these provide equity across crews, predictability for a crew, and long, contiguous periods of time off that should help combat the onset of chronic fatigue. Step-by-step instructions for implementing these two sample schedules are shown in Appendices B and D, respectively.

The most important audience for this TM is the aircrew scheduler. The expected audience also includes commanders, safety officers, aerospace physiologists, flight surgeons and aircrew. In addition to tactical airlift operations, the guidance here may be useful for other 24/7 intra-theater flight operations. This guidance takes into account Chapter 9 (Crew Rest and Crew duty Limitations), Air Force Instruction 11-202, Volume 3, Flying Operations, General Flight Rules, 6 June 2003, and emphasizes the implementation of Paragraph 9.7.4, Exceptions to the 12-Hour Minimum Crew Rest Period.

Show times and crew duty periods (CDPs) were available from Miller (2005). Approximately one-quarter of show times occurred at night (0001 through 0600; Table 1), causing truncation of the major sleep period. Another 18% occurred in the evening (1801 through 0000), with the high probability that no nocturnal sleep would follow. Sleep truncation and deprivation of nocturnal sleep are two primary sources of cumulative fatigue. 41% of the missions showed this potential. **Recommendation:** Move show times from the Night and Evening periods into the Morning and Afternoon periods whenever possible.

TABLE 1. Distribution by quarters of the clock of show times for 61 C-130 missions (from Miller, 2005)

	Show Time	Number	Proportion
Night	0001-0600	14	23%
Morning	0601-1200	26	43%
Afternoon	1201-1800	10	16%
Evening	1801-0000	11	18%

Crew duty Periods averaged 10+26 (h+min) but varied widely, with a 6+34 standard deviation and right skew (i.e., more flights were shorter than were longer than 10+26). Only 13% of CDPs exceeded 14 hours (Table 2). This is an encouraging finding, suggesting that only about 1 mission in 7 (for example, one mission per crew per 2 weeks) requires a CDP greater than 14 h. The finding indicates that AFI 11-202, Paragraph 9.7.4, Exceptions to the 12-Hour Minimum Crew Rest Period, may be put into play here to help reduce the

² Miller JC (2005). *Aircrew Fatigue In 24/7 Intra-Theater Operations (FOUO)*. Technical Report AFRL-HE-BR-TR-200x-00xx, Air Force Research Laboratory, Brooks City-Base TX, in review.

occurrence of cumulative fatigue. **Recommendation:** Keep CDP at 14 h or less. If not possible, use a crew scheduled for a day off after the CDP to fly a CDP greater than 14 h.

TABLE 2. Distribution of crew duty periods (from Miller, 2005).

Length (h)	Number	Proportion
<= 6	4	7%
<= 12	34	56%
<= 14	15	25%
<= 16	7	11%
<= 18	1	2%

The reported use of aircrews as “schedulers” was of concern (Miller, 2005). Rapid turnover in a scheduling function leads to a loss of corporate memory and inefficient scheduling. Inefficient schedules lead to fatigue, and fatigue has been implicated in more than 150 USAF Class A mishaps over the last 25 years. The rotating schedules outlined in this memo are more complex to read than to implement at the Wing and Squadron levels. However, as is true for any other such scheduling function, they would be implemented and maintained best with good corporate memory. **Recommendation:** Use permanent party for the core of the scheduling team.

METHODS

The calculations in this TM were based upon the U.S. Department of Defense Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) applied model. The SAFTE applied model integrated the effects of length of prior wakefulness, amount of sleep and circadian rhythm. This applied model was implemented in the Windows program, Fatigue Avoidance Scheduling Tool (*FAST*TM, NTI Inc., Dayton OH), which was used to make the calculations and to draw the figures shown in this Memorandum.

The *FAST*TM graphs in this TM depict a cognitive effectiveness prediction (left-hand vertical axis) as a function of time (horizontal axis). Work periods are shown as red bands on the horizontal axis and reflected up as wider red portions on the cognitive effectiveness prediction. Sleep periods are shown as blue bands across the horizontal axis.

The cognitive effectiveness prediction is for composite human performance on a number of cognitive tasks such as logical reasoning and mental arithmetic. The prediction (left-hand) axis is scaled up to 100%. The oscillating black and red line in the diagram represents expected group average performance (throughput) on cognitive tasks. We would expect the predicted performance of half of the people in a group to fall below this line.

The green area on the chart ends at the time for normal sleep, about 90% effectiveness. Our goal is to keep operation above this line during safety-sensitive work such as flying, driving, operating weapons, and making command and control decisions. The red area on the chart represents performance effectiveness after 2 days and a night of sleep deprivation. Workers in this area are highly likely to fall asleep on the job.

The thin red line is referenced to the right-hand vertical axis, scaled from 0001h at the bottom, through noon to midnight at the top. This plot shows the process of re-alignment of the body's circadian rhythm phase with the day-night cycle in the new time zone.

AIRCREW SCHEDULING

Solely from the human perspective, 24/7, intra-theater aircrew scheduling requires no different thinking than shiftwork scheduling. We have a principle-based, quantitative approach to shiftwork scheduling. We have been directed by the Air Staff to publish this approach in an Air Force Manual, now in preparation.³ Some aspects of the scheduling principles and concepts from the Manual were applicable here.

However, manpower limitations (i.e., the limited number of aircrews), aircraft maintenance problems and availability, flight operation constraints and aircrew currency problems make the problem of 24/7, intra-theater aircrew scheduling more complex than the shiftwork scheduling problem. This difference may be dealt with simply by allowing flexibility in aircrew schedules that is not present in shiftworker schedules. However, this flexibility must be constrained so that the cumulative fatigue experienced by a given aircrew does not become dangerous. That is, the scheduling approach must be selected with care, scheduling principles must be used as goals, and scheduling concepts must guide the implementation of the schedule.

The focus here is on the individual aircrew. It is the shared responsibility of both the scheduler and the aircraft commander (AC) to assure that flexibility in scheduling does not cause needless cumulative fatigue for the AC's crew. Thus, the sequence of duty and rest periods for the individual crew must be examined carefully. Fortunately, a systematic approach to scheduling helps to assure that all individual crew schedules are acceptable.

SCHEDULING APPROACHES

There are three approaches to 24/7 scheduling: fixed shifts, rapidly rotating shifts and slowly rotating shifts. If the organization is fortunate enough to find enough qualified people to work permanent nights, who prefer that shift, then the fixed shift solution may be viable and successful. However, only a tiny proportion of the population prefers night work over day work. Forcing permanent shifts on unwilling personnel leads to inequities that, in turn, trigger poor morale, job performance and personnel retention. The assumption made here was that some sort of a rotating shift is necessary.

If adequate day-sleep facilities are available and the aircrews are educated about sleep hygiene, then the slowly-rotating schedule is best (i.e., shift rotation no more quickly than once every two weeks). If adequate day-sleep facilities are not available, then the rapidly-rotating schedule is best (i.e., shift rotation every day or two). The latter minimizes the

³ Recommendation made by the Inspector General of the Air Force and approved by the Air Staff. The recommendation was included in the final report of the AFIA Eagle Look PN 04-602, May 2004, "Shift Worker Fatigue." It was Recommendation Ob 1-1 "Update and adapt the Fundamentals of Shift Work Scheduling Manual into an AFMAN.(OPR: SAF/AQ [AFMC/AFRL])"

exposure to inherently debilitating night work. Unfortunately, the extra time required to rotate from one shift to the next in a rapidly-rotating schedule is subtracted from contiguous periods of time off in any given full rotation cycle of work and free days.

SCHEDULING PRINCIPLES

Seven scheduling principles were applied here:

1. Set a normal, maximum CDP of 14 hours to allow a crew to work on a 24-h cycle. [An exception (i.e., CDP of 16 hours) may be made when the crew is scheduled for a day off after the CDP.] Adherence to this principle allows the synchronization of the human circadian rhythm with the local day-night cycle, helping to minimize jet lag and associated sleep deprivation, and it is consistent with AFI 11-202, Paragraph 9.7.4.1.
2. Follow each CDP longer than 14 h with a day off. Adherence to this principle reduces cumulative fatigue and is consistent with AFI 11-202, Paragraph 9.7.6.2.
3. Schedule either:
 - A long sequence of night shifts in a slowly-rotating schedule (with adequate sleep facilities) to allow acclimation to night work and day sleep, or
 - A minimum number of consecutive night shifts in a rapidly-rotating schedule to minimize exposure to night work where sleeping facilities are inadequate.
 - **Note:** The word, rotation, refers to a change, for example, from a day shift to a night shift.
4. In a rapidly-rotating system, follow each night shift with 24 hours off. Realize that the 24 hours off is a recovery period from have stayed up all night. Thus, the quality of this time off for the worker tends to be low.
5. Schedule long, contiguous periods of time off. These long periods are generally viewed by the aircrew as being of "good quality." It is also possible that long, contiguous periods of time off help minimize the likelihood of chronic fatigue occurrence⁴. However, note that long, contiguous periods of time off also require compressed work schedules.
6. Assure equity by giving all aircrews equal demands for long CDPs and night work and equal access to day work and good quality time off.
7. Schedule an aircrew such that their show time does not differ more than +/- 1 hour on successive days to allow the crew to continue on a 24-h cycle.

SCHEDULING CONCEPTS

Five scheduling concepts were considered here:

1. Number of crews and manning ratio,
2. The relative numbers of work and free days,
3. Crew duty period (CDP) and crew workload,
4. The sequence of work and free days, and
5. Show times.

⁴ CHRONIC MENTAL FATIGUE is a factor when the individual is exposed frequently during at least one month to multiple periods of prolonged wakefulness, excessive work hours, disturbed or shortened major sleep periods, unresolved conflicts, or prolonged frustration and it degrades task performance. An individual must display, concurrently, four or more of the following symptoms: the desire to sleep, apathy, substantial impairment in short-term memory or concentration; muscle pain; multi-joint pain without swelling or redness; headaches of a new type, pattern or severity; unrefreshing sleep; and post-exertional malaise lasting for more than 24 hours. The symptoms must have persisted or recurred for at least one month. [It is not eliminated by any number of sleep periods without first removing the cause.]

Number of Crews and Manning Ratio

As reported in Miller (2005), crews flew about 7 missions in 2 weeks or one mission every other day. Data suggested a manning ratio of about 2.5 crews per assigned mission. And 4 or 5 crews assigned to scheduling duties and to stand alerts. These limited data indicated that the 2.5 crews per mission were reduced by 10% to 2.25 crews per mission to cover scheduling and alerts. Probably another 10% overage was allowed for administration and training. Leave was discounted here due to the expeditionary nature of the duty. Thus, the manning ratio appeared to be just sufficient for two crews per assigned mission and for an individual crew to be scheduled to fly on half of 80% of all days and to spend 10% of their days assigned to scheduling or alert and to spend another 10% of their days available for administrative duties or training. Days scheduled for scheduling, alert, administration and/or training are referred to as "A" days in the remainder of this memorandum.

The Relative Numbers of Mission and Non-Mission Days

Given the calculations above, scheduling probably has been and should continue to be based upon the assignment of equal numbers of mission and non-mission days to an individual crew. For example, in a 30-day "month," all crews should expect to be scheduled to fly on 12 days and to spend 6 days in some combination of scheduling, alert, administrative duties, and training (A days).

Crew Duty Period (CDP) and Crew Workload

On the surface, the idea of an aircrew flying on only 40% of the days deployed, as calculated above, may be a bit disturbing. Office workers work on 71% of the days of each week. However, when the length of the CDP is factored in, it makes sense. For example, on average, the 14-h CDP translates into about 39 hours per week of flying duties. The A days are added to this number of work hours.

The data in Table 2 indicated that more than half of all missions will probably have a CDP shorter than 14 h. This allows the implementation of the principle of scheduling show times that differ up to 1 hour earlier on one or two successive days. Thus, paragraph 9.7.4.1 of AFI 11-202 is implemented here for slowly-rotating schedules:

9.7.4.1. For continuous operations when basic aircrew CDPs are greater than 12 but less than 14 hours, subsequent crew rest may be reduced proportionally to a minimum of 10 hours in order to maintain a 24-hour work/rest schedule.

9.7.4.1.1. Continuous operations are defined as three or more consecutive CDPs of at least 12 hours duration separated by minimum crew rest.

9.7.4.1.2. The 10-hour crew rest policy is only to be used to keep crews in their 24-hour clock cycles, not for scheduling conveniences or additional sortie generation.

9.7.4.1.3. Any reduction from 12 hours crew rest requires pre-coordination of transportation, meals and quarters, so that crewmembers are provided an opportunity for at least 8 hours of uninterrupted sleep.

Show Times

For convenience, we split the day into quarters or eighths. This split allows the implementation of the principle of equity across crews.

Note: The quarters of the clock are the approximate equivalent of shifts in shiftwork, except that they refer to show times, not to the entire work period.

Within one quarter or eighth of the day, use known, daily scheduling experience to link crews with specific hours, plus or minus one hour. That is, for the Night quarter, a crew would be linked initially to a show time of 0100, 0300 or 0500 +/-1 hour; for first eighth of the day, a crew would be linked to a show time of 0130 +/-1 hour, etc.

SLOW ROTATION EXAMPLE

First, we tackle the slowly-rotating schedule for crews with good sleeping quarters. This example is based upon a 120-day deployment, split into shift rotations that are proportional with respect to the mission demands shown in Table 1, above, for show times within different quarters of the day. For the present example, any crew entering the system would expect to spend (23% of 120 days =) 28 days with show times in the Night quarter, 52 days in the Morning quarter, 19 days in the Afternoon quarter, and 21 days in the Evening quarter. Rotations from one quarter to the next would always be forward on the clock (i.e., with later show times in each subsequent rotation). For example, a crew might start on the Morning quarter, then rotate through the Afternoon, Evening and Night quarters, in that order.

Note: A mission demand table such as Table 1 should probably be re-calculated on a period that is half the deployment length. Thus, for a 120-day deployment, 60 days of data would be summarized as in Table 2 and adjustments made to the proportions of deployment time spent in each quarter of the clock.

Mission days (M) and days off (O) should each occupy 40% of a rotation, and A days should occupy 20%. The crew would be scheduled for a maximum 14-h CDP and 10 h of crew rest on all mission days, but allowances are made, below, for several longer CDPs. The mission days should be compressed together to allow night-flying aircrews to attempt to acclimate to night work and day sleep and to recover during long, contiguous periods of time off. Thus, the 28-day sequence might be 6 mission days, 1 day off, 5 mission days, 5 days off, 5 A days, and 6 days off. All mission days occur in the first half of the rotation for half of the crews while all mission days occur in the second half of the rotation for the other half of the crews:

Half of crews: M M M M M M O M M M M M O O O O A A A A O O O O O O
Half of crews: O O O O O A A A A A O O O O O O M M M M M M O M M M M M

The O days that immediately follow M days may be moved among the M days to accommodate preceding CDPs longer than 14 h, if needed. The A days may be a mixture of scheduling, alert, administrative duties, and training, and the A and O days may also be re-sequenced, as needed. However, the scheduler should recognize that long, contiguous periods of time off will be viewed as valuable by aircrews and may help delay or prevent the onset of chronic fatigue.

How do we assure equity of assignments to the four quarters of the clock across aircrews in this slowly-rotating schedule? All crews spend the same, proportional number of days of their deployments with show times in each of the four quarters of the clock.

How does the scheduler assure that all quarters of the clock have the planned number of crews? Since each individual crew spends a different number of days in each quarter of the clock, the rotations are asynchronous. That is, all crews cannot rotate from one quarter to the next on the same day. Thus, a rotation plan is needed. The basis for the plan is the ratio of the number of days to the number of crews assigned gives the spacing between crews in the rotation schedule. The ratio may be based either upon days and crews in a quarter of the clock or upon the numbers of days and crews in the deployment. In our example, 10 crews are needed in the Night quarter and each crew should spend 28 days with show times in that quarter. Thus, the 10 Night quarter crews should be spaced $(28 / 10 =)$ about 3 days apart in their progress through the rotation and Morning quarter crews should be spaced about $(52 / 19 =)$ about 3 days apart in their progress through the cycle. Similarly, the 44 total crews in this example should be spaced $120 / 44 = 3$ days apart, rounded up from 2.7 days. A sample snapshot of one day in a rotation is shown in Appendix A.

Note: In practice, a crew that has a series of 13-h or shorter CDPs could have show times that move earlier (or later) several hours within a quarter across several mission days, at a rate of no more than 1 hour per day.

Note: In practice, a crew could migrate past the boundary of a quarter. For example, a Morning 0700 crew with a series of 13-h or shorter CDPs could be scheduled earlier on two sequential days and become a 0500 crew, operating in the Night quarter. The strength here is the scheduler's ability to adjust manning across quarters, as needed. The weakness is the potential loss of equity of assignments to quarters of the clock for the affected crew. Thus, the scheduler should plan to migrate the crew back to its original quarter before the end of the crew's rotation in that quarter.

Note: What do you do if your plan does not match up with the Air Tasking Order? If you already have a reasonable schedule for your aircrew resources, based upon your daily experience, it (1) will be close, and (2) will give you leverage for negotiations with higher headquarters. Your squadron can and should say things such as, "We can fly that mission, but we will not be bringing the crew on duty until an hour after (or before) your scheduled show time. Please adjust your plans accordingly." If you have your plan in front of you when the ATO comes in, you have 12 hours in which negotiations can occur. Very few of these missions have absolute and precise time requirements: even scheduled airlines have to adjust for maintenance and weather problems, and this is no scheduled airline. The customers depending upon your airplanes should adjust their schedules a bit for preventive crew maintenance (i.e., better-quality crew rest), if needed.

Caution: Avoid a slow drift of the show time for a given crew either earlier or later across days. Make no more than two hours of change in one direction of change across two days before reversing the direction of change. Keep the crew as close as possible to a single show time.

RAPID ROTATION EXAMPLE

Second, we tackle the rapidly-rotating schedule for crews with poor sleeping quarters. Much of the information and methods associated with the slowly-rotating schedule are applicable here, including the use of the 14-h CDP and 10-h crew rest period, the nominal show time +/- 1 hour and the work demand shown in Table 1.

The objective here is to minimize exposure to night work. Ideally, the crew would work only one night and then have a day off. The worst-case night mission involves landing(s) during the pre-dawn hours, about 0200 to 0600. Landings are somewhat more likely to occur in the 7th through 13th hours of the CDP. This translates into show times in the period 1300 to 2300. Thus, we wish to minimize sequential exposures to show times of 1300 through 2300. In the data that made up Table 1, sorted further by 3-hour blocks (eighths of the day; Table 3), 35% (roughly one-third) of the show times occurred in this period.

TABLE 3. Distribution by 3-h blocks of show times for 61 C-130 missions.

Nominal Show Time	Period	Number	Proportion	Rotations
01:30	00 < 03	7	11%	1
04:30	03 < 06	7	11%	1
07:30	06 < 09	22	36%	4
10:30	09 < 12	4	7%	1
13:30	12 < 15	6	10%	1
16:30	15 < 18	4	7%	1
19:30	18 < 21	4	7%	1
22:30	21 < 00	7	11%	1

The manning and flying frequency results from the slow-rotation example taught us that we need equal numbers of M and O days, and about 20% A days. Combining these with the one-third portion of “night” show times suggests schedule a cycle with two “day” missions (M_D; 0100-1100 show times), one “night” mission (M_N; 1300-2300 show times) and three days off (O). Two 6-day, M-and-O cycles plus 3 A days would be needed to allow us to approximate the 20% duty day requirement (20% of 15 days is 3 days). Thus, the combined cycle would be 15 days long and look something like this:

M_DM_DM_NOOD M_DM_DM_NOODD

The O-A pairs may be re-sequenced, as needed.

How do we assure equity across aircrews in this rapidly-rotating schedule? Assign each crew initially to a nominal (+/-1 h) day show time for the first 15-day rotation, then assign them to the next available nominal day show time for the next 15-day rotation. This may be the same

show time as before if they were showing at 0730 +/- 1.5 h when mission demands are high (Table 3), or it may be the next later nominal show time. For example, a crew might spend one rotation each in the 0130 and 0430 show times, four rotations in the 0730 show time, and 1 rotation in the 1030 show time. In this case, it would take a crew $(1+1+4+1 =) 7$ rotations, or $(7 \times 15 \text{ days} =) 105$ days, to work through all possible show time assignments. A sample snapshot of one day in a rotation is shown in Appendix J.

Note: In this rapid-rotation example, the show time for a night mission may vary simply as a function of preceding crew rest requirement following the second day mission.

Caution: Avoid a slow drift of the show time for a given crew either earlier or later across days. Make no more than two hours of change in one direction of change across two days before reversing the direction of change. Keep the crew as close as possible to a single show time, especially toward the end of a cycle.

SUMMARY AND RECOMMENDATIONS

There are three approaches to 24/7 scheduling: fixed shifts, rapidly rotating shifts and slowly rotating shifts. The assumption made here was that some sort of a rotating shift was necessary. Seven scheduling principles were applied:

- Set a normal, maximum crew duty period (CDP) of 14 hours (AFI 11-202, Paragraph 9.7.4.1).
- Follow each CDP longer than 14 h with a day off (AFI 11-202, Paragraph 9.7.6.2).
- Schedule either:
 - A long sequence of night shifts in a slowly-rotating schedule (with adequate sleep facilities) to allow acclimation to night work and day sleep, or
 - A minimum number of consecutive night shifts in a rapidly-rotating schedule to minimize exposure to night work where sleeping facilities are inadequate.
- In a rapidly-rotating system, follow each night shift with 24 hours off.
- Schedule long, contiguous periods of time off.
- Assure equity by giving all aircrews equal demands for long CDPs and night work and equal access to day work and good quality time off.
- Schedule an aircrew such that their show time does not differ more than +/- 1 hour on successive days to allow the crew to continue on a 24-h cycle.

Five scheduling concepts were used to produce an example of a slowly-rotating schedule and an example of a rapidly-rotating schedule. The concepts were:

- Number of crews and manning ratio,
- The relative numbers of work and free days,
- Crew duty period (CDP) and crew workload,
- The sequence of work and free days, and
- Show times.

The memo includes one example of a slowly-rotating schedule for crews with good day-sleep quarters and one example of a rapidly-rotating schedule for crews with poor day-sleep quarters. Schedules such as these provide equity across crews, predictability for a crew, and long, contiguous periods of time off that should help combat the onset of chronic fatigue.

Recommendations:

- Use permanent party for the core of the scheduling team.
- Move show times from the Night and Evening periods into the Morning and Afternoon periods whenever possible.
- Keep CDP at 14 h or less. If not possible, use a crew scheduled for a day off after the CDP to fly a CDP greater than 14 h.
- If adequate day-sleep facilities are available and the aircrews are educated about sleep hygiene, then the slowly-rotating schedule is best (i.e., shift rotation no more quickly than once every two weeks). If adequate day-sleep facilities are not available, then the rapidly-rotating schedule (i.e., shift rotation every day or two) should be used to minimize exposure to inherently debilitating night work.

APPENDIX A
Sample 1-Day Slow Rotation Status Table for 44 Crews
(next page)

Notes:

1. The table shows a snapshot of one day of crew progress through the four rotations, Night, Morning, Afternoon, and Evening.
2. D# represents the elapsed day of the rotation for the specific crew.
3. Crews do not move out of the assigned nominal show time cell within one rotation. However, their actual show times may vary up to +/-1 hour per day.
4. Half of the crews would be in the non-flying half of their rotation.
5. In this example, four crews would rotate to their next quarter on every third day if all crews stay synchronized. For example, on the day after the one shown in the table, Crew J would move from Night show times to Day 1 (D1) in a cell of the Morning quarter, Crew AC would move to D1 in a cell of the Afternoon quarter, Crew AJ would move to D1 in a cell of the Evening quarter, and Crew AR would move to D1 in a cell of the Night quarter (after an extra day off because of the 21-day length of the Evening rotation).

Quarter:	Night			Morning			Afternoon			Evening		
Nominal Show +/-1 hour:	01	03	05	07	09	11	13	15	17	19	21	23
Crews												
A	D1											
B	D4											
C	D7											
D		D10										
E		D13										
F		D16										
G			D19									
H			D22									
I			D25									
J			D28									
K				D1								
L				D4								
M				D7								
N				D10								
O				D13								
P				D16								
Q					D19							
R					D22							
S					D25							
T					D28							
U					D31							
V					D34							
W						D37						
X						D40						
Y						D43						
Z						D46						
AA						D49						
AB						D52						
AC						D52						
AD							D1					
AE							D4					
AF								D7				
AG								D10				
AH									D13			
AI									D16			
AJ									D19			
AK										D1		
AL										D4		
AM										D7		
AN											D10	
AO											D13	
AP											D16	
AQ												D19
AR												D21

APPENDIX B

Implementing the Slow Rotation

1. This schedule is for crews with good sleeping quarters.
2. **Number of crews and manning ratio:** Observation indicates that manning is approximately 2.5 crews per daily mission. Thus, a crew will be scheduled to fly on 40% of the days and to pull other duties and training on 20% of the days during the deployment. Other manning ratios will affect the relative numbers of work and free days and the sequence of same, below. However, the same arithmetic still applies.
3. **The relative numbers of work and free days:** 40% mission days (M), 40% days off (O) 20% A days. For the actual numbers of days:
 - 3.1. Start with M days: multiply the shift length by 0.40, and round up to the nearest integer. For example, for the 19-day shift, the integer length for 0.40×19 is 8 days, rounded up from 7.6 days.
 - 3.2. Then calculate A days, rounding up. For example, for the 19-day shift, 0.20×19 is 4 days, rounded up from 3.8 days.
 - 3.3. The remainder of the days are O days. In this example, $19 - 8 - 4 = 7$ days.

Note: We round up because it will be more acceptable to cancel work on a scheduled mission or duty day for a crew than to insert work into their schedule.

4. **Crew duty period (CDP):** maximum 14-h CDP and 10 h of crew rest on all mission days (but allowances are made automatically for several longer CDPs).
5. **Show times:** Calculate "shift" rotation lengths that are proportional with respect to expected mission demands during the deployment (120 days long in this example):

TABLE B-1. Distribution by quarters of the clock of show times for missions over the last 30 to 60 days, and planned numbers of days on shift (**Note:** this is an example; calculate your own distribution).

Show	Time	Number	Proportion	Days on Shift
Night	0001-0600	14	23%	28
Morning	0601-1200	26	43%	52
Afternoon	1201-1800	10	16%	19
Evening	1801-0000	11	18%	21
TOTAL		61		120

- 5.1. Rotations from one quarter to the next are always forward on the clock (i.e., with later show times in each rotation).
- 5.2. Within each quarter of the clock, use your known, daily scheduling experience to link crews with the first, third and fifth hours of the quarter, plus or minus one hour. That is, for the Night quarter, a crew would be linked initially to 0100, 0300 or 0500, +/-1 hour; for the Morning quarter, a crew would be linked to 0700, 0900 or 1100, +/-1 hour, etc.

Note: In practice, a crew that has a series of 13-h or shorter CDPs could have show times that move earlier (or later) several hours within a quarter across several mission days, at a rate of no more than 1 hour per day.

Note: A crew may migrate past the boundary of a quarter. However, plan to migrate the crew back to its original quarter before the end of the crew's rotation in that quarter.

Caution: Avoid a slow drift of the show time for a given crew either earlier or later across days. Make no more than two hours of change in one direction of change across two days before reversing the direction of change. Keep the crew as close as possible to a single show time.

6. **The sequence of work and free days for the shift:** Compress M and A days together, respectively. In all cases, a crew's O days may be moved among their M and A days to cover missions in the ATO. However, emphasize the compression of M and A days into sequences strongly.

- 6.1. Sample 28-day sequence (12M, 6D, 10O):

Half of crews: MMMMMOMMMMOO OOOAAAAA OOOOO

Half of crews: OOOOOAAAAA OOO OOMMMMMOMMMMM

- 6.2. Sample 52-day sequence (21M, 11D, 20O):

Half of crews:

MMMMMMMOOMMMMMMMMOOMMMMMMO OOOOOAAAAA OOOO ODDDDDD OOOOO

Half of crews:

OOOO ODDDDDD OOOOOAAAAA OOOOO MMMMMMOOMMMMMMMMOOMMMMMMMMO

- 6.3. Sample 19-day sequence (8M, 4D, 7O):

Half of crews: MMMMMMOO OOOOAAAAO

Half of crews: OOOOAAAAO MMMMMMOO

- 6.4. Sample 21-day sequence (9M, 5D, 7O):

Half of crews: MMMMMOMMMMO OOOAAAAAO

Half of crews: OOOAAAAAO MMMMMOMMMMO

Note: The A days may be a mixture of scheduling, alert, administrative duties, and training, and the A and O days may be re-sequenced, as needed.

7. **Rotation from shift to shift:** The ratio of the number of days to the number of crews assigned gives the spacing between crews in the rotation schedule. The ratio may be based upon days and crews in a quarter of the clock or upon days and crews in the deployment. In our example, 10 crews are needed in the Night quarter and each crew should spend 28 days with show times in that quarter. Thus, the 10 crews should be spaced $28 / 10 = 3$ days apart, rounded up from 2.8 days, through the rotation. Similarly, the 44 total crews in this example should be spaced $120 / 44 = 3$ days apart, rounded up from 2.7 days. Four crews would rotate to their next quarter on every third day if all crews stay synchronized, which is recommended to minimize management time and efforts.

8. **Make a table** of the crew schedule as shown in Appendix E. Using date arithmetic in a spreadsheet, this table can be constructed to update a crew's rotation day with respect to the rotation start date and the computer's system date.
9. **Starting and maintaining the rotation:** Choose a day to start. Initially, assign all crews to one position in the crew schedule table using a quasi-random system that takes into account the immediate need for crew rest on the start day. When a crew departs the deployment and is replaced by another crew, put the new crew in the same spot and rotation day vacated by the departing crew.

APPENDIX C
Sample 1-Day Rapid Rotation Status Table for 44 Crews
(next page)

Notes:

1. The table shows a snapshot of one day of crew progress through the four rapid rotations.
2. D# represents the elapsed day of the rotation for the specific crew.
3. Crews do not move out of the assigned nominal show time cell within one rotation. However, their actual show times may vary up to +/-1 hour per day.
4. Crews spend 1 day on all shifts except the 07:30 shift, where they spend 4 days.
5. Crews may be assigned to any of the four 07:30 time slots in subsequent rotations.

Nominal Show +/-1 hour:	1:30	4:30	7:30	10:30	13:30	16:30	19:30	22:30
Crews								
A	D1							
B	D1							
C	D1							
D	D1							
E		D1						
F		D1						
G		D1						
H		D1						
I			D1					
J			D1					
K			D1					
L			D1					
M			D2					
N			D2					
O			D2					
P			D2					
Q			D3					
R			D3					
S			D3					
T			D3					
U			D4					
V			D4					
W			D4					
X			D4					
Y				D1				
Z				D1				
AA				D1				
AB				D1				
AC					D1			
AD					D1			
AE					D1			
AF					D1			
AG						D1		
AH						D1		
AI						D1		
AJ						D1		
AK							D1	
AL							D1	
AM							D1	
AN							D1	
AO								D1
AP								D1
AQ								D1
AR								D1

APPENDIX D

Implementing the Rapid Rotation

1. This schedule is for crews with poor sleeping quarters.
2. **Number of crews and manning ratio:** Observation indicates that manning is approximately 2.5 crews per daily mission. Thus, a crew will be scheduled to fly on 40% (2.5^{-1}) of the days and to pull other duties and training on 20% of the days during the deployment. Other manning ratios will affect the relative numbers of work and free days and the sequence of same, below. However, the same kind of arithmetic still applies.
3. **The relative numbers of work and free days:** 40% mission days (M), 40% days off (O) 20% A days.
4. **Crew duty period (CDP):** maximum 14-h CDP and 10 h of crew rest on all mission days (but allowances are made automatically for several longer CDPs).
5. **Show times:** Calculate "shift" rotation lengths that are proportional with respect to expected mission demands (Table I-1):

TABLE C-1. Distribution by 3-h blocks of show times for missions over the last 30 to 60 days, and planned numbers of days on shift (**Note:** this is an example; calculate your own distribution).

Nominal Show Time	Period	Number	Proportion	Rotations	Crews
01:30	00 < 03	7	11%	1	4
04:30	03 < 06	7	11%	1	4
07:30	06 < 09	22	36%	4	16
10:30	09 < 12	4	7%	1	4
13:30	12 < 15	6	10%	1	4
16:30	15 < 18	4	7%	1	4
19:30	18 < 21	4	7%	1	4
22:30	21 < 00	7	11%	1	4

6. **The sequence of work and free days for the shift:** A crew should work only one night and then have a day off. Minimize sequential exposures to show times of 1300 through 2300. In Table I-1, roughly one-third of the show times occurred in this period. In this example, we can use a cycle with two "day" missions (M_D ; 0100-1100 show times), one "night" mission (M_N ; 1300-2300 show times) and three days off (O). Two 6-day, M-and-O cycles plus 3 A days are needed to approximate the 20% duty day requirement (20% of 15 days is 3 days). The combined cycle is 15 days long:

$M_D M_D M_N O O O A M_D M_D M_N O O O A A$

Note: In this rapid-rotation example, the show time for a night mission may vary simply as a function of preceding crew rest requirement following the second day mission.

Note: The A days may be a mixture of scheduling, alert, administrative duties, and training, and the A and O days may be re-sequenced, as needed, to meet the ATO.

7. **Rotation from shift to shift:** Assign each crew initially to a nominal (± 1 h) day show time for the first 15-day rotation, then assign them to the next available nominal day show time for the next 15-day rotation. This may be the same show time as before if they were showing at 0730 ± 1 h when mission demands are high (Table 4), or it may be the next later nominal show time.
8. **Make a table** of the crew schedule as shown in Appendix E. Using date arithmetic in a spreadsheet, this table can be constructed to update a crew's rotation day with respect to the rotation start date and the computer's system date.

Note: Rotations from one shift to another are always forward on the clock (i.e., with later show times in each rotation).

Note: In practice, a crew that has a series of 13-h or shorter CDPs could have show times that move earlier (or later) several hours within a shift across several mission days, at a rate of no more than 1 hour per day.

Note: A crew may migrate past the boundary of the 07:30 shift. However, plan to migrate the crew back into the 07:30 shift (06:00 to 09:00) before the end of the crew's rotation in that shift.

Caution: Avoid a slow drift of the show time for a given crew either earlier or later across days. Make no more than two hours of change in one direction of change across two days before reversing the direction of change. Keep the crew as close as possible to a single show time, especially toward the end of a cycle.

9. **Starting and maintaining the rotation:** Choose a day to start. Initially, assign all crews to one position in the crew schedule table using a quasi-random system that takes into account the immediate need for crew rest on the start day. When a crew departs the deployment and is replaced by another crew, put the new crew in the same spot and rotation day vacated by the departing crew.